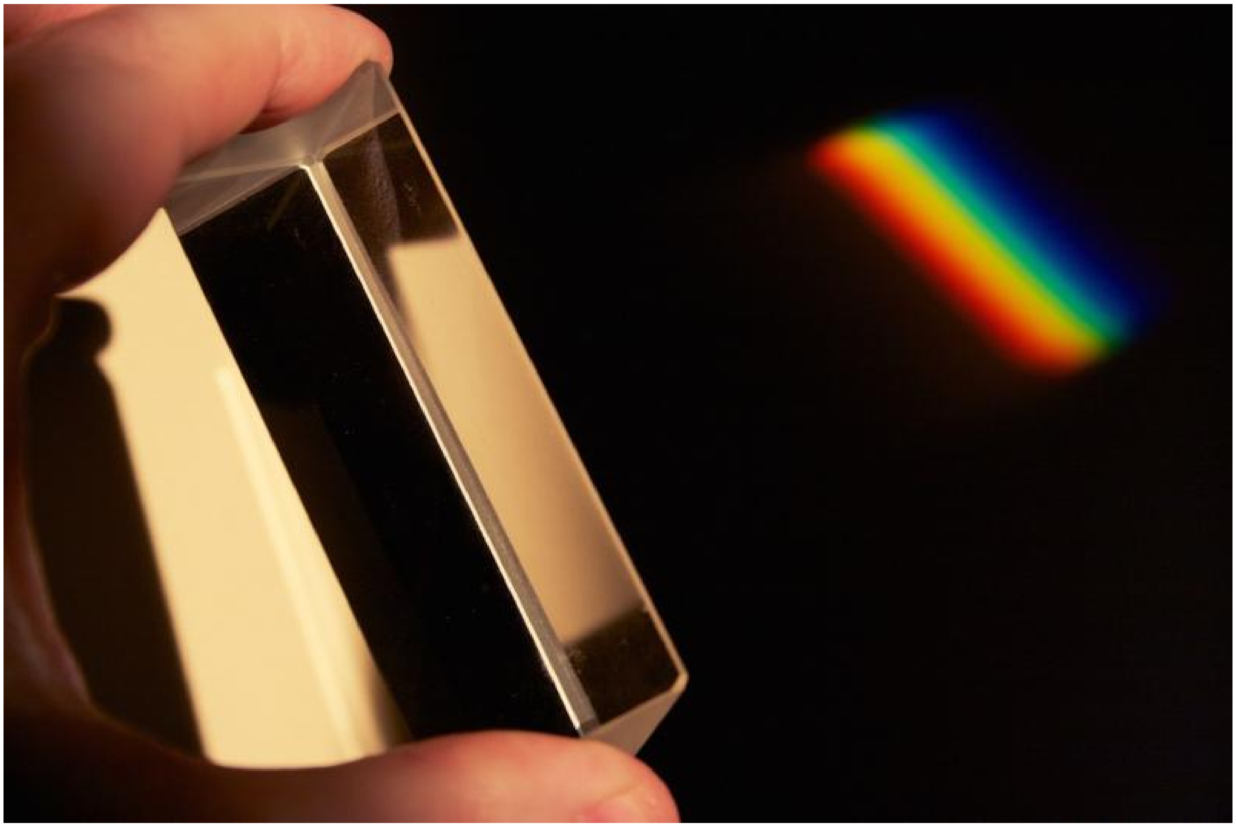
# Seeing the universe through spectroscopic eyes

July 17 2015, by Amanda Bauer



The colours of the spectrum revealed as the light passes through a glass prism. Credit: Flickr/final gather, CC BY-ND

When you look up on a clear night and see stars, what are you really looking at? A twinkling pinprick of light with a hint of colour?

Imagine looking at a starry sky with eyes like prisms that separate the light from each star into its full rainbow of colour. Astronomers have built instruments to do just that, and spectroscopy is one of the most powerful tools in the astronomer's box.

The technique might not produce the well-known pretty pictures sent down by the Hubble Space Telescope, but for astronomers, a spectrum is worth a thousand pictures.

Visible spectra reveal huge amounts of information about objects in the distant cosmos that we can't learn any other way.

## So what is spectroscopy?

Spectroscopy is the process of separating starlight into its constituent wavelengths, like a prism turning sunlight into a rainbow. The familiar colours of the rainbow correspond to different wavelengths of visible light.

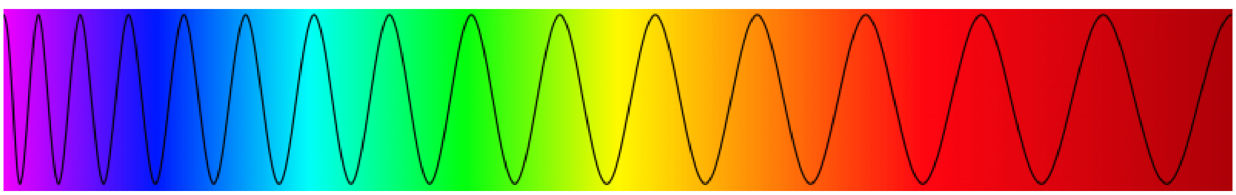
The human eye is sensitive to the visible spectrum – a narrow range of frequencies among the entire electromagnetic spectrum. The visible spectrum covers wavelengths of roughly 390 nanometers to 780 nanometers (astronomers often use units of Angstroms ($10^{-10}$), so visible light spans 3,900 to 7,800 Angstroms).

Once visible starlight reaches the curved primary mirror of a telescope, it is reflected toward the focal point and can then be directed anywhere. If the light is sent directly to a camera, an image of the night sky is seen on a computer screen as a result.

If the light is instead sent through a spectrograph before it hits the camera, then the light from the astronomical object gets separated into its basic parts.

A very simple spectrograph was used by Issac Newton in the 1660s when he dispersed light with a glass prism. Modern spectrographs consist of a series of optics, a dispersing element and a camera at the end. The light is digitised and sent to a computer, which astronomers use to inspect and analyse the resulting spectra.

The video (above) shows the path of distant starlight through the 4-metre Anglo-Australian Telescope (AAT) and a typical spectrograph, revealing real data at the end.



The spectrum of visible light. Note the wavelength increases towards the red. Credit: Wikimedia, CC BY

## What do spectra teach us?

A spectrum allows astronomers to determine many things about the object being viewed, such as how far away it is, its chemical makeup, age, formation history, temperature and more. While every astronomical object has a unique rainbow fingerprint, some general properties are universal.

Here we examine the galaxy spectra shown in the video. The spectrum of a galaxy is the combined light from its billions of stars and all other radiating matter in the galaxy, such as gas and dust.

In the top spectrum you can see a few strong spikes. These are called "emission lines" and occur at discrete wavelengths due to the atomic structure of atoms as electrons jump between energy levels.

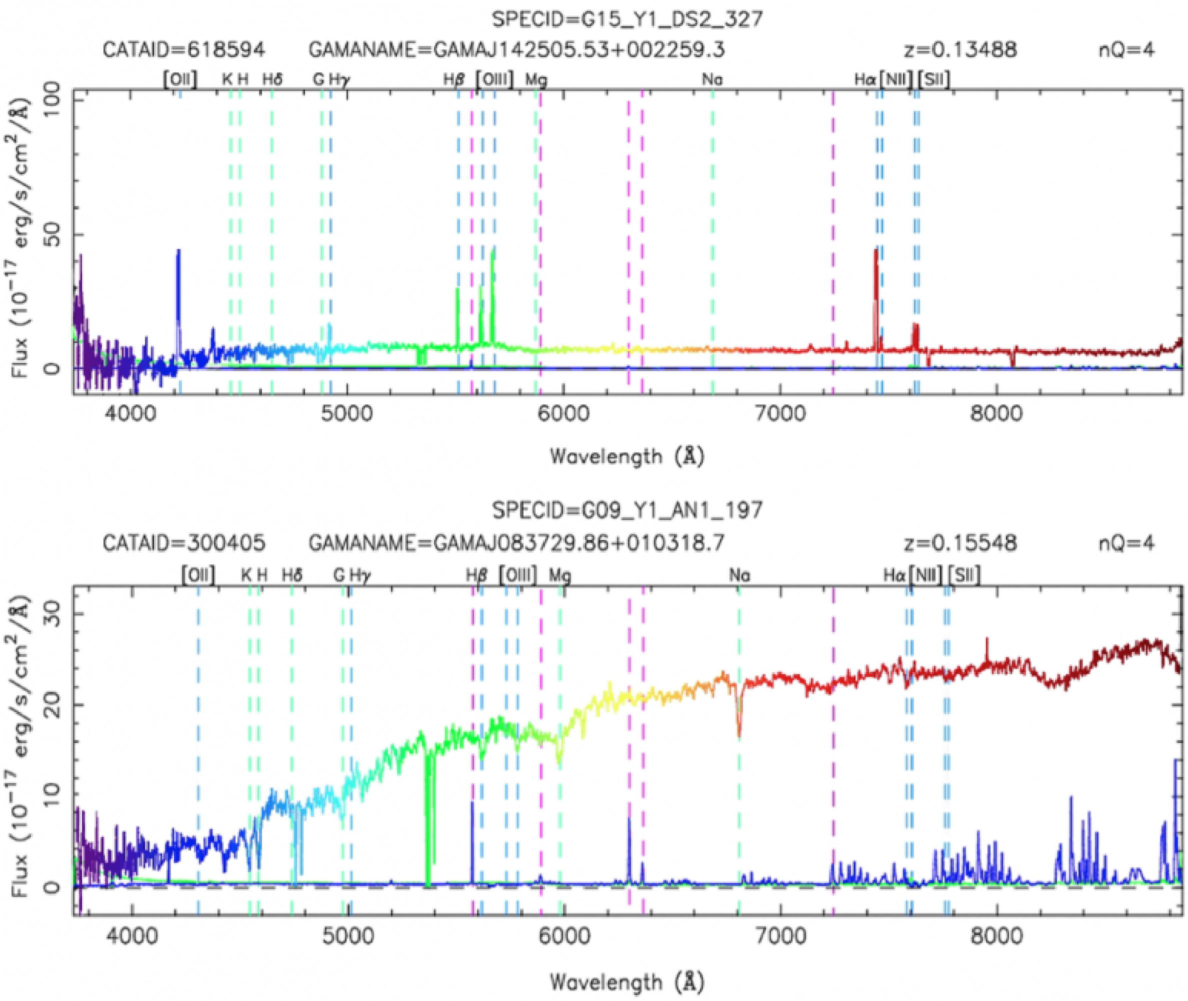
The hydrogen spectrum is particularly important because 90% of the normal matter in the universe is hydrogen. Because of the details of hydrogen's atomic structure, we recognise the strong hydrogen-alpha emission line at roughly 7,500 Angstroms in the top spectrum image.

In a galaxy, only the youngest, biggest stars are hot enough to excite surrounding hydrogen gas enough that the electrons populate the third energy level, before falling to the second lowest, thus emitting a hydrogen-alpha photon.

Because of this, we know the strength of the hydrogen-alpha line in a galaxy's spectrum indicates how many very young stars there are in the galaxy. Since the bottom spectrum shows no hydrogen-alpha emission, we can conclude that the bottom galaxy is not sparking new life in the form of shining stars, while the top galaxy harbours several hard working stellar nurseries.

In the bottom spectrum you can see a number dips. These are called "absorption lines" because they appear in the spectrum if there is anything between the light's source and the observer on Earth absorbing the light. Absorbing material could be the extended layers of a star or interstellar clouds of gas or dust.

The absorption lines close to each other below 5,000 Angstroms in the bottom spectrum are the calcium H and K lines and can be used to determine how quickly stars are zooming around the galaxy.



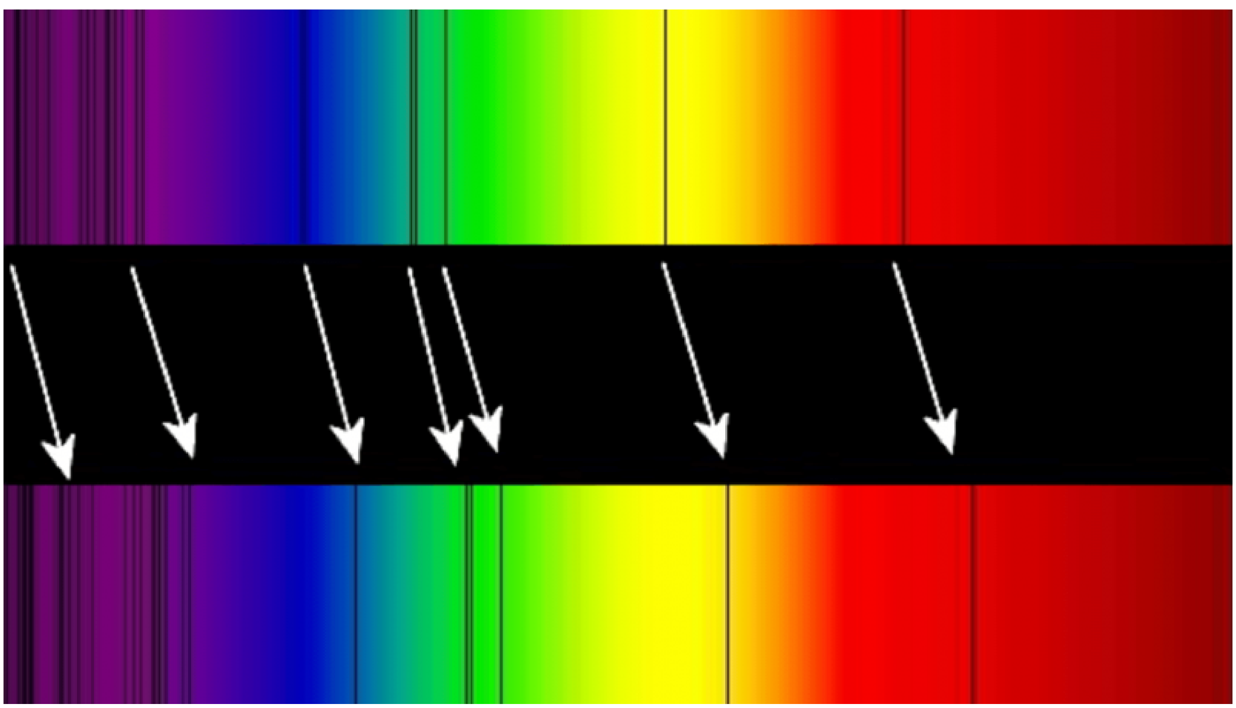

Top shows a spiral galaxy spectrum. Bottom shows non-star-forming galaxy spectrum. Credit: Australian Astronomical Observatory video, Author provided

## In a galaxy how far away?

A basic piece of information derived from a spectrum is the distance to the galaxy, or specifically, how much the light has stretched during its journey to Earth. Because the universe is expanding, the light emitted by the galaxy is stretched toward redder wavelengths as it innocently moves across space. We measure this as redshift.

To determine the exact distance of a galaxy, astronomers measure the well-studied pattern of absorption and emission lines in the observed spectrum and compare it to the laboratory wavelengths of these features on Earth. The difference tells how much the light was stretched, and therefore how long the light was travelling through space, and consequently how far away the galaxy is.

In the top galaxy spectrum mentioned earlier, we measure the strong red emission line of hydrogen-alpha to be at a wavelength of roughly 7,450 Angstroms. Since we know that line has a rest wavelength of 6,563 Angstroms, we calculate a redshift of 0.13, which means the light was travelling for 1.7 billion years before it reached our lucky telescope. The galaxy emitted that light when the universe was roughly 11.8 billion years old.



The absorption lines ‘shift’ the farther away an object is, giving us an indication of its distance from us. Credit: Georg Wiora (Dr. Schorsch)/Wikimedia

**Australia's strength in spectroscopy**

Australia has led the way internationally for spectroscopic technology development for the last 20 years, largely due to the use of fibre optics to direct galaxy light from the telescope structure to the spectrograph.

A huge advantage of using optical fibres is that more than one spectrum can be obtained simultaneously, drastically improving the efficiency of the telescope observing time.

Australian astronomers have also led the world in building robotic technologies to position the individual optical fibres. With these, the AAT and the UK Schmidt Telescopes (both located at Siding Spring Observatory in New South Wales) have collected spectra for a third of all the 2.5 million galaxy spectra that humans have ever observed.

While my own research uses hundreds of thousands of galaxy spectra for individual projects, it still amazes me think that each one of these spectra are composite collections of light created by hundreds of billions of stars gravitationally bound together in a single swirling galaxy, many similar to our own Milky Way home.

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